

Solid Earth

ES-3 The student will demonstrate an understanding of the internal and external dynamics of solid Earth.

Key Concepts for ES-3:

Origin-Formation of Earth's Systems: gravitational force, heat production; nebular theory

Earth's Layers: core – inner & outer; mantle – lithosphere, asthenosphere, crust

Theory of Plate Tectonics: convection currents; plate boundaries; scientific evidence

Crustal changes: earthquake activity; volcanic eruptions; mountain building

Geologic processes: weathering, erosion, deposition, glaciation

Rock Cycle: divisions of the rock cycle; processes that form types of rocks

Mineral & Rock classification: properties of mineral & rocks;

Ores: formation

Fossil fuels: formation – coal, petroleum, natural gas; environmental impact

ES-3.1 Summarize the theories and evidence of the origin and formation of Earth's systems by using the concepts of gravitational force and heat production.

Taxonomy level: 2.4-B Understand Conceptual Knowledge

Previous/future knowledge: Students have not been introduced to the concepts in this indicator in any previous grade.

It is essential for students to know that according to the *nebular theory* (gravitational condensation theory), Earth was formed as a planet in the solar system from material in the solar nebula that condensed and compacted due to gravitation force.

- Shortly after Earth formed, the decay of radioactive elements and the heat released by colliding particles produced some melting of the rocky material that made up Earth.
- The denser elements, mainly iron and nickel, sank due to gravity to Earth's center, while the lighter, rocky components floated outward toward the surface. This sorting of material by density is believed to be continuing on a smaller scale even today.
- Gaseous materials were allowed to escape from Earth's interior. By this process an atmosphere gradually formed, composed chiefly of gases expelled from within the planet.

Other theories include the planetesimal theory and the tidal theory.

Earth's systems are today powered by energy from the Sun and also from Earth's internal heat. After the formation of the atmosphere and hydrosphere the Sun's energy drives the systems in the atmosphere, hydrosphere, and at Earth's surface. Heat remaining from when Earth formed and that is continuously generated by the decay of radioactive elements, powers the internal processes that produce volcanoes, earthquakes, and mountains.

It is not essential for students to know the details of other theories that do not involve gravitational force and heat production.

Assessment Guidelines:

The objective of this indicator is to *summarize* major points about the formation of Earth; therefore, the primary focus of assessment should be to generalize major points about the nebular theory as it relates to gravitational force and heat production.

In addition to *summarize* appropriate assessments may require students to:

- *compare* the formation of Earth based on various theories;
- *sequence* the events in the formation of Earth; or
- *compare* material that makes up the core with that found in the crust.

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ES-3.2 Explain the differentiation of the structure of Earth's layers into a core, mantle, and crust based on the production of internal heat from the decay of isotopes and the role of gravitational energy.

Taxonomy level: 2.7-B Understand Conceptual Knowledge

Previous/future knowledge: Students in 8th grade (8-3.1) understood the structure of the layers of Earth on the basis of position, density, and composition. Students have not been introduced to the reasons for this differentiation of internal structure.

It is essential for students to know that the layering of Earth into core, mantle and crust occurred early in Earth's formation because the temperature within the planet steadily increased due to decay of radioactive elements.

- Earth became so hot that at least some melting of original materials occurred and denser materials were pulled to the core.
- Heat from the core and radioactivity within the mantle keep the mantle hot.
- The gradual increase in temperature and pressure within Earth affects the physical properties and the mechanical behavior of Earth materials.
- Therefore, depending upon the temperature and pressure, a particular Earth material may behave like a solid, or like a puttylike material, or even melt and become a liquid in various Earth layers.

Core: The heavier material sank to become the core. At the extreme pressures found in the core, the iron-rich material becomes very dense. The solid inner core and the liquid outer core make up nearly one third of Earth's mass. The convective flow of metallic iron in the outer core generates Earth's magnetic field. Despite its high temperature, the material in the inner core under immense pressure behaves like a solid.

Mantle: The mantle is a zone of rock that makes up almost two-thirds of Earth's mass. It is divided into different regions – the top portion, along with the crust, is mostly igneous rock and is part of the *lithosphere*. The *asthenosphere*, below the lithosphere, is partially melted due to increases in pressure and temperature. In the lower mantle pressure increases and the rock material strengthens to a more rigid layer. Even so, the rocks are still hot and capable of very gradual flow.

Crust: Earth's outermost layer is the crust, a relatively cool, rigid shell. It makes up only about one percent of Earth's mass. There are two types of crustal material – oceanic crust and continental crust.

The behavior of seismic waves has allowed scientists to learn much about Earth's interior structure.

It is not essential for students to know the temperatures or distances for each of the layers.

Assessment Guidelines:

The objective of this indicator is to *explain* the structure of Earth's layers; therefore, the primary focus of assessment should be to construct cause and effect models of how the production of internal heat and the role of gravitational energy effect the structure of Earth's crust, mantle, and core.

In addition to *explain* appropriate assessments may require students to:

- *compare* the layers of Earth;
- *sequence* the layers; or
- *identify* the layers or sub-layers based on properties.

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ES-3.3 Summarize the theory of plate tectonics (including the role of convection currents, the action at plate boundaries, and the scientific evidence for the theory).

Taxonomy level: 2.4-B Understand Conceptual Knowledge

Previous/future knowledge: Students in 8th grade (8-3.6) were introduced to the theory of plate tectonics with the motion of the lithospheric plates and geologic activities at the plate boundaries. Students have not been introduced to the internal driving forces or to the scientific evidence for the theory.

It is essential for students to know the theory of plate tectonics states that Earth's crust and rigid upper mantle are broken into enormous sections called plates. Tectonic plates move in different directions and at different rates over Earth's surface. The plates are continually changing in shape and size.

Role of Convection Currents:

What causes Earth's plates to move is explained in a hypothesis that proposes convection currents within the mantle.

The movement of the plates is driven by the unequal distribution of heat within Earth that set up convection currents within the upper mantle.

- Hot material found deep in the mantle moves slowly upward and serves as one part of Earth's internal convection system.
- Also cooler, denser sections of oceanic lithosphere descend into the mantle, setting the outer crust into motion.
- The asthenosphere, below the lithosphere, is partially melted due to an increase in temperature. (The partial melting is due to increasing temperature without sufficient increase in pressure to prevent melting. Temperatures below the asthenosphere are higher, but material is not melted because pressures are too high to allow it.)
- Convection currents in the asthenosphere are thus set in motion by the transfer of energy between Earth's hot interior and the cooler exterior.

There are still many unanswered questions about mantle convection currents.

Action at Plate Boundaries:

When tectonic plates move, they interact at places called plate boundaries. Each type of boundary has certain geologic characteristics and processes associated with it.

Divergent Boundaries are places where two plates are moving apart (separating).

- Most are found on the sea floor and form ocean ridges.
- The formation of new crust occurs at most divergent boundaries and accounts for high heat flow, volcanic eruptions, and earthquakes.
- On continents when continental crust begins to separate, the stretched crust forms a long, narrow depression called a rift valley.

Convergent Boundaries are places where two plates are moving toward each other. There are three types, which are classified by the type and density of crust involved:

- *Oceanic crust converging with oceanic crust* – one of the two plates becomes denser due to cooling and descends beneath the other in a process called subduction that creates a deep trench and a volcanic arc of islands. The subducted plate descends into the mantle and melts, thus recycling the crustal material.

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- *Oceanic crust converging with less dense continental crust* – subduction also occurs but the subduction causes a trench and a mountain range with many volcanoes along the continent's edge.
- *Continental plates collide* – both plates are too buoyant to be subducted, so the colliding edges of the continents are crumpled and uplifted to form a mountain range.

Transform Boundaries are places where two plates slide horizontally past each other.

- At these boundaries crust is only deformed or fractured.
- Most transform boundaries are not found on continents; a famous exception is the San Andreas Fault in southwest California.

Scientific Evidence for the Theory:

Evidence for the plate tectonic theory began with early observations made about the shape of the continents. A *continental drift hypothesis* was developed. Evidence for this hypothesis included similar rock types and formations on continents now separated, as well as similar fossils of several different animals and plants that once lived on land now found to be widely separated continents. That hypothesis was originally rejected because the force great enough to move continents could not be shown but as more evidence was gathered, it was revisited and leads to today's *plate tectonics theory*.

In the 1960s evidence was found on the seafloor that could explain how continents move.

- *Seafloor spreading* is a theory stating that new ocean crust is formed at ocean ridges where magma rises to the surface and hardens.
 - A new section of crust forms which slowly moves away from the ridge.
 - Crust is destroyed, re-melted, at deep-sea trenches.
- *Magnetic striping* patterns emerged as scientists collected data about the areas parallel to the ocean ridges.
 - The magnetic pattern on one side of the ridge matched the pattern on the other.
 - Scientists were able to determine the age of the ocean floor from the magnetic recording.
 - Relatively new ocean floor crust is found near ocean ridges,
 - and older ocean crust is found along deep-sea trenches.

TEACHER NOTE: Even though it is not specifically stated in the indicator, a knowledge of some of the major plates, their locations, and relative motion helps students to identify plate boundaries and the formations and activities that are evident along the plate boundary in that region of Earth.

It is not essential for students to know the explorations that took place to acquire the information for the theory of plate tectonics.

Assessment Guidelines:

The objective of this indicator is to *summarize* major points about the theory of plate tectonics; therefore, the primary focus of assessment should be to generalize major points about the role of convection currents, the actions at plate boundaries, and evidence for the theory.

In addition to *summarize* appropriate assessments may require students to:

- *compare* the actions at the various plate boundaries;
- *illustrate* with drawings or diagrams the geologic characteristics and processes at plate boundaries;
- *recall* evidence from the early continental drift hypothesis.

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ES-3.4 Explain how forces due to plate tectonics cause crustal changes as evidenced in earthquake activity, volcanic eruptions, and mountain building.

Taxonomy level: 2.7-B Understand Conceptual Knowledge

Previous/future knowledge: Students in 8th grade (8-3.7) illustrated the creation and changing of landforms due to volcanic eruptions and mountain-building forces but it was not necessarily tied to the forces due to plate tectonics.

It is essential for students to know that many crustal changes occur because of the forces interact at and within plate boundaries.

- *At diverging boundaries*, where forces on the plates are pulling them apart, new crustal material forms as volcanic eruptions bring magma up to the surface. Earthquakes often accompany a volcanic eruption. Undersea mountain ridges are built from this activity as magma cools and hardens.
- *At converging boundaries*, the force of plates being pushed together may form deep undersea trenches. Volcanic eruptions occur as some magma is forced back to the surface to form either volcanic arcs or volcanoes within mountain ranges. Converging forces may slowly push continental crust against continental crust so that the land crumples and folds to form a mountain range.
- *Along transform fault boundaries*, as plates slide past each other, the build up of pressure along the boundary may cause the fault to quickly move resulting in an earthquake.
- Some volcanoes are located far from plate boundaries in regions known as *hot spots*.
 - These are formed where high-temperature mantle material rises toward the surface in plumes that melt crustal rock turning it to magma.
 - The magma melts through the crust to form volcanoes.
 - A trail of older volcanoes forms as a plate moves over a hot spot, such as the Hawaiian Islands.
 - Chains of volcanoes that form over hot spots provide important information about plate motions, such as rate and direction.

Students may find the study of the hot spot beneath the Yellowstone Basin in Wyoming an interesting study.

It is not essential for students to know about forces that cause crustal change and activities within tectonic plates.

Assessment Guidelines:

The objective of this indicator is to *explain* crustal changes due to the forces of plate tectonics; therefore, the primary focus of assessment should be to construct cause and effect models of how tectonic forces could result in earthquake activity, or volcanic eruptions, or mountain building. In addition to *explain* appropriate assessments may require students to:

- *interpret illustrations* to determine the cause of the feature; or
- *summarize* activities that occur to Earth's crust because of plate tectonic forces.

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ES-3.5 Analyze surface features of Earth in order to identify geologic processes (including weathering, erosion, deposition, and glaciation) that are likely to have been responsible for their formation.

Taxonomy level: 4-B Analyze Conceptual Knowledge

Previous/future knowledge: Students in 5th grade (5-3.1) explain how natural processes of weather erosion, and deposition affect Earth's oceans and land in constructive and destructive ways. In 8th grade (8-3.9) students identified and illustrated geologic features as viewed using imagery and topographic maps. Students have not been introduced the process of glaciation nor its resulting features.

It is essential for students to use illustrations, imagery, topographic maps, pictures, or descriptions of surface features to determine geologic processes responsible for those features.

Weathering is a process that includes both the disintegration and decomposition of surface rock material.

- *Disintegration* is the physical or mechanical breakdown of Earth materials; the original material has not been changed, just its size or shape. Rocks may be cracked, broken, or peeled off through mechanical weathering.
- *Decomposition* is the chemical altering of the composition of the material. Acids, water, carbon dioxide, or oxygen may react with the rock material causing the change.

Erosion is a process that moves weathered material from one place to another.

- Various erosion agents (gravity, wind, water, plants/animal/humans) pick up Earth materials and carry them to other locations.
- Erosion is a destructive process that wears down Earth's surface.
- Gullies, rills, changes in coastal topography, sand dunes, and landslides are evidence of erosion by those various agents.

Deposition is a process is closely related with erosion because they are dependent on one another.

- The agent that eroded the material in one place will deposit it in another.
- It is a constructive process that builds up Earth's surface.
- Deltas and sandbars or barrier islands are a result of deposition.

Glaciation is a process has the capacity to carry huge rocks and piles of debris over great distances.

- Glaciers scrape and gouge out large sections of Earth's landscape.
- Features left in the wake of glaciation include U-shaped valleys, waterfalls, glacial lakes, and various types of deposits such as moraines.

It is not essential for students to know the names for individual processes of weathering, erosion, or glaciation – just the broad concepts.

Assessment Guidelines:

The objective of this indicator is to *analyze* surface features of Earth to identify the geologic processes responsible for their formation; therefore, the primary focus of assessment should be to determine from material presented the relevant information that would determine the cause for a particular geologic feature or the change that occurred to a geologic feature.

In addition to *analyze* appropriate assessments may require students to:

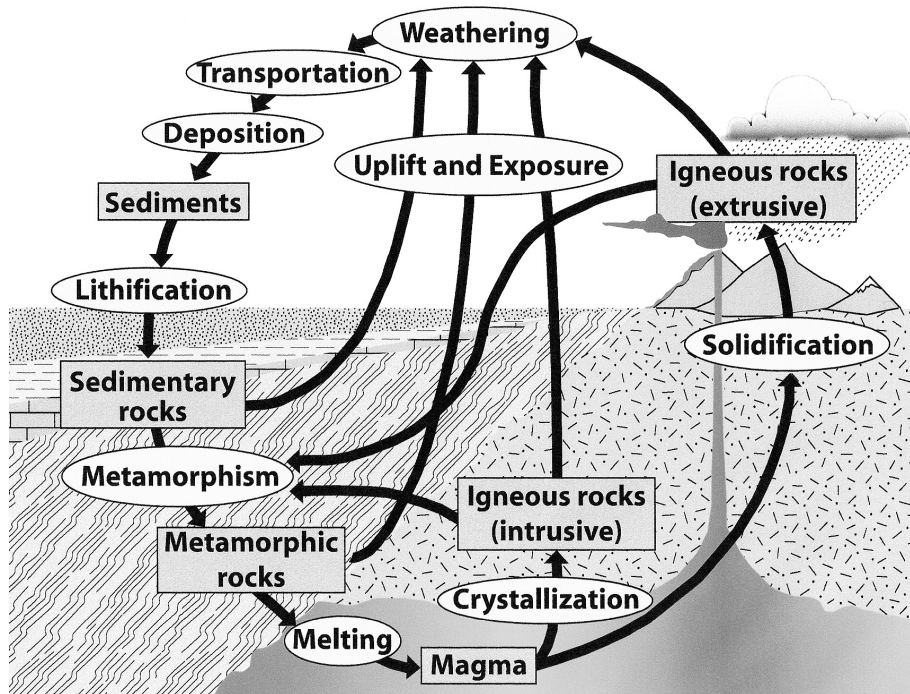
- *compare* the processes of weathering, erosion, and deposition;
- *summarize* the processes that change the surface features of Earth; or
- *identify* features of glaciation.

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Taxonomy level: 2.7-B Understand Conceptual Knowledge

It is essential for students to know that the rock cycle illustrates the continuous changing and remaking of rocks on Earth. The rocks of Earth, whether they are at the surface or below the crust, are always positioned somewhere on the rock cycle.

- The three types of rock – igneous, sedimentary, and metamorphic – are grouped according to how they form. These rock types form the divisions of the rock cycle.
- Processes can change any rock into another rock.
 - Internal processes include heat & pressure, melting, cooling & crystallization, and uplift.
 - External processes include weathering, erosion, deposition, burial, and lithification.



<http://www.dnr.sc.gov/geology/images/rocks.pdf>

The objective of this indicator is to *explain* the dynamic nature of the rock cycle; therefore, the primary focus of assessment should be to construct cause and effect models of how surface and internal processes account for formation, change and reforming of rocks on Earth.

- *compare* the processes that could form or change each type of rock;
- *recognize* internal and external processes that change rocks; *or*
- *identify* a type of rock by the process that formed it.

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ES-3.7 Classify minerals and rocks on the basis of their physical and chemical properties and the environment in which they were formed.

Taxonomy level: 2.3-B, C Understand Conceptual-Procedural Knowledge

Previous/future knowledge: Students in 3rd grade (3-3.1) classified rocks into one of the three types based on physical properties and identified minerals (3-3.2) by properties on an identification key. In 8th grade (8-3.4) the three rocks types were explained through the rock cycle and the importance of minerals (8-3.5) summarized based on physical and chemical properties. Students have not classified mineral or rocks using an identification process.

It is essential for students to know the processes and properties that allow for mineral identification and rock identification. They should be able to use mineral and rock identification keys/charts.

Mineral Identification:

Geologists rely on several relatively simple tests to identify minerals. These tests are based upon a mineral's physical and chemical properties. By using the results from a combination of tests rather than just one, the mineral's classification and identity is more accurate. Comparing test results from the mineral sample with known properties of minerals from a mineral identification chart increases the accuracy of the identification.

Mineral identification properties and tests students should be able to perform include:

- color,
- luster,
- texture,
- streak,
- hardness, and
- cleavage & fracture.
- Density tests may also be performed if the right equipment is available. Heft (heaviness compared to sample size) is sometimes used as a relative density description.
- Some minerals have special properties that are useful in identification, such as reaction with acid, magnetic attraction, or light refraction in transparent or translucent minerals.

Rock Identification:

Rocks are made up of minerals and are formed very differently, therefore their identification and classification is fairly complicated. Geologists must analyze mineral composition, evidence of type of formation, and size & arrangement of minerals to determine the classification of rocks. After basic information is gathered on a specific rock to determine its major rock type and classification, properties on a rock identification chart can be used to identify the specific rock sample.

Rock identification properties and tests students should be able to perform include:

- For **igneous** rocks – determine if the igneous rock is *intrusive* or *extrusive* based on - texture (fine-grained, coarse grained, glassy crystal size); composition of minerals (using common minerals such as quartz, feldspar, mica, hornblende).
- For **metamorphic** rocks – determine if the metamorphic rock is *foliated* or *nonfoliated* based on – texture (layers or bands of minerals, not banded); coarse-grained or fine-grained
- For **sedimentary** rocks – determine if the sedimentary rock is *clastic*, *organic*, or *chemical* based on – evidence of sediment particles/grains (coarse-grained, medium-grained, fine-grained) cemented together; evidence of once-living material (shells, plants/carbon,); evidence that the material could have been precipitated or settled out of water or was evaporated from solution.

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The properties of the rocks also give clues to the environment in which they were formed.

- Intrusive igneous rocks with their larger crystals were formed deep inside Earth where slow cooling could take place. Small grained or glassy texture of extrusive igneous rocks indicates rapid cooling at Earth's surface with little to no time for crystals to grow.
- The grade of metamorphic rock is dependent upon a combination of factors including pressure on the rocks, the temperature, and the depth below the surface.
- Clastic sedimentary rocks with particles that are rounded are evidence of water transported materials while angular fragments indicated little transport or possibly wind born.
- Changes in river level or sea level may result in stratification of sedimentary rock layers.

It is not essential for students to do further classification of minerals into groups/families or to identify specific mineral crystal systems. The composition or origin of magma or the process of crystallization is not essential, although students may find crystal growing an interesting activity. Further classification of igneous, metamorphic, or sedimentary rocks beyond the main grouping is not necessary.

Assessment Guidelines:

The objective of this indicator is to *classify* minerals and rocks; therefore, the primary focus of assessment should be to use physical and chemical properties of minerals and of rocks to determine which category the sample belongs and also the environment in which it was formed.

In addition to *classify* appropriate assessments may require students to:

- *identify* a mineral property based on its description;
- *explain* how the formation environment affects crystal size or grain texture; or
- *interpret* information on a mineral or rock identification chart.

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ES-3.8 Summarize the formation of ores and fossil fuels and the impact on the environment that the use of these fuels has had.

Taxonomy level: 2.4-B Understand Conceptual Knowledge

Previous/future knowledge: Students in 8th grade (8-3.5) summarized the importance of ores and fossil fuels because of their physical and chemical properties. Students have not been introduced to how these materials formed or to the impact that their use has had on the environment.

It is essential for students to know how ores and fossil fuels form.

Ore formation:

A metal element or mineral is an *ore* if it contains a useful substance that can be mined at a profit.

- Ores form within Earth's crust as magma cools.
- Dense metallic minerals sink to the bottom of a body of magma.
- Layers of minerals accumulate and form ore deposits within the hardened magma.
- Hot mineral solutions may also spread through small cracks in rock and harden in fingerlike bands called *veins* or *lodes*.

Fossil fuel Formation:

Because of their organic origin, coal, petroleum, and natural gas are called *fossil fuels*.

- *Coal* is a dark-colored organic rock formed from the remains of plants that flourished millions of years ago.
 - Usually dead plants decompose, but if oxygen in a swamp area is limited and decay rate is slow, the compressed organic matter becomes coal.
- *Petroleum* and *natural gas* originated with once living organisms that died and their remains accumulated on the ocean floor and lake bottoms, buried by sediments.
 - As with coal, limited oxygen prevented the remains from decomposing completely.
 - As more and more sediments accumulated, heat and pressure increased becoming great enough to convert the remains into petroleum and natural gas.

Fossil fuels, like minerals, are nonrenewable resources that are needed in our world today, but the obtaining and use of these fuels can have an impact on the environment:

- Coal is the most abundant fossil fuel in the world. The present reserves of coal should last about 200 years.
 - *Anthracite* coal is the most efficient, cleanest burning coal, but it has the smallest reserves.
 - Most coal burned is *bituminous*.
 - The burning of all types of coal releases carbon, sulfur, and nitrogen oxides into the air causing air pollutions and acid precipitation, so safeguards are important to keep the abundance of these oxides from the air.
 - Strip mining of coal leaves deep ditches where the coal is removed, so mining companies work to ensure that the land around the mine is reclaimed as close to its natural state as possible.
- Petroleum production involves looking for oil traps in folds of the rock layers or in fracture or fault zones.
 - Oil shale contains petroleum between its layers, but the cost is great to mine it.
 - Transporting of oil must be done with care so that oil spills from tankers and pipelines do not pollute ocean waters or harm wildlife.

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Assessment Guidelines:

The objective of this indicator is to *summarize* the formation of ores and fossil fuels and also to *summarize* the impact these fuels have had on the environment; therefore, the primary focus of assessment should be to generalize the major points about the formation of ores and fossil fuels and environmental impact issues regarding the use of fossil fuels.

In addition to *summarize* appropriate assessments may require students to:

- *exemplify* ways that fossil fuels impact the environment; or
- *identify* the types of fossil fuels.